
Hazard-Rating Systems In Forest Insect Pest Management:

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INTRODUCTION

The Douglas-fir beetle (DFB), *Dendroctonus pseudotsugae* Hopk., occurs throughout most of the distribution of its principal host, Douglas-fir (DF), *Pseudotsuga menziesii* (Mirb.) Franco (fig. 1). Western larch, *Larix occidentalis* Hook, is also infested, but progeny survive only in felled larch.

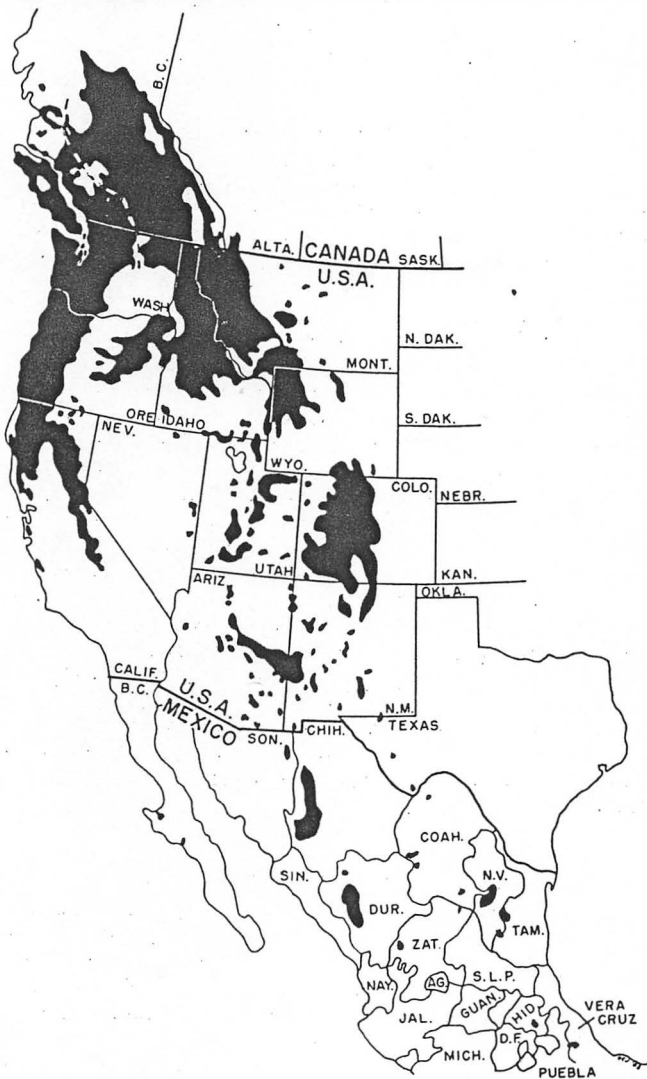


Figure 1.--Geographic distribution of Douglas-fir.

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The DFB is univoltine, overwintering mainly as callow adults (Furniss and Orr 1978). It is a robust flier, taking flight early in spring as air temperature warms above 65° F. We have observed flights of 6 hours' or more duration at an average velocity of 2.5 mph (4 km/hr) on flight mills. Thus, DFB are capable of dispersing several kilometers in a single flight, permitting them to reach susceptible stands at some distance from population sources.

Much literature about the beetle has been compiled (Furniss 1979), including information related to host susceptibility. However, no susceptibility classification has been published relating probability of mortality to descriptors of trees, stands, or sites.

This paper deals, in order of emphasis, with the natural basis for a susceptibility classification, field methodology, and analyses. This information was developed during long-term research from examinations of many hundreds of trees, particularly in Idaho, and from the cited works of others. Nonetheless, we have only recently begun a concerted effort to develop a more holistic approach to defining mathematically the probabilities of mortality, given various stand data. Thus, at the time of this symposium, we have not concluded fieldwork and our probability example is based on a limited data set. We believe, however, that the natural basis for the classification and the field methodology will be of interest and will foster communication with others.

When our present work is completed, we will compare in a future publication the probabilities of mortality derived from a more adequate sample base from stands representing a broader range of edaphic, climatic, and floristic conditions. We are confident that the outcome will provide protection specialists and resource managers with better means of classifying stands in need of silvicultural treatments and other practices to prevent DFB from killing trees. Concurrently, we hope to provide an avenue for understanding the processes responsible for or related to presence or absence of DFB infestation.

NATURALISTIC BASIS FOR CLASSIFICATION

In this section, we present information on beetle behavior, characteristics

of infested trees and groups, and predisposing agents. That information forms the natural basis for our seeking to relate descriptors of sites and stands to DFB susceptibility.²

Aggregation Behavior

The DFB typically attacks groups of trees, not single trees. Group killing results from aggregation of beetles to pheromones secreted by unmated females that have begun invading their hosts (Pitman and Vité 1970, Pitman et al. 1975). Attractiveness of those pheromones is synergized by resin odors, primarily α -pinene (Furniss and Schmitz 1971). Attraction is terminated when the antiaggregative pheromone MCH is released after mating (Rudinsky and Ryker 1976).

Number of trees killed per group varies with abundance of beetles and extent of susceptible trees. During outbreaks, infested groups increase in size: a single group may include well over 100 trees. Normally groups do not enlarge after the year of attack because the beetles disperse to more susceptible units of surrounding stands. This discrete pattern may be altered somewhat when susceptible stands are contiguous or extensive, beetles are exceptionally abundant, or root disease is prevalent.

Because aggregative pheromones cause beetles to attack groups of trees, we are developing a stand classification rather than an individual tree classification. However, data are taken from individual trees in developing the stand classification.

Host Specificity

The species and chemical characteristics of natural hosts of the DFB provide insight into what makes a tree or stand susceptible. Only two species of trees are known to produce DFB broods in nature: Douglas-fir and western larch. Hopkins (1921) listed big cone Douglas-fir (*Pseudotsuga macrocarpa* [Vasey] Mayr) as a host in southern California, but that record cannot be verified. In Chihuahua, Mexico, *Pseudotsuga flahaulti* Flous is a host (Furniss 1981), although it is doubtfully distinct from *P. menziesii* (Little 1979).

² We distinguish between susceptibility to attack (which we define as attractiveness of the host tree) and susceptibility to successful attack. The distinction will be apparent in subsequent discussion.

Sometimes, western larch trees are attacked--always unsuccessfully--when growing among DF that are under DFB attack (fig. 2). Freshly felled larch is a good host, though. DFB broods emerge from larch at rates equal to broods from DF (Furniss 1976).



Figure 2.--Unsuccessful resin-impregnated egg galleries in live western larch.

Live DF and western larch have similar monoterpenes in their resin (Hanover and Furniss 1966, Stairs 1968). Both possess a large amount of α -pinene, and the average amounts of four other monoterpenes are similar. As noted earlier, α -pinene greatly increases attractiveness of aggregative pheromones.

It seems reasonable to explain the infestation of live western larch by the presence of intermingled odors from neighboring attacked DF and the similarity of the trees' monoterpene content. That is, beetles arrest on trees in the vicinity of attractant odors; some arrested females are stimulated to construct egg galleries by "familiar" monoterpenes present in larch resin. But we still do not know why broods fail to survive in live larch. Solving that puzzle may contribute to developing improved preventive methods, per-

haps by genetic selection of Douglas-fir trees containing the resistant mechanism that is universal in live larch.

Susceptibility of Attacked Trees

We recognize three categories of susceptibility of trees in infested groups: susceptible, intermediate, and resistant. Susceptible trees are readily killed. Their egg galleries are free of resin, and their foliage discolors within approximately 1 year. Such trees yield DFB progeny at the highest rates. Intermediate trees eventually die, apparently from inoculation with fungi carried by beetles (Harrington et al. 1981, Rumbold 1936). Foliage of some trees of this category discolors more slowly, sometimes in the second year following attack. Resistant trees survive; their galleries are impregnated with resin and eventually are covered over by callous growth (Belluschi et al. 1965) (fig. 3).

Table 1 compares the characteristics of 739 attacked trees in all three categories, in western Montana. The trees averaged 188 years in age. We obtained similar data from somewhat younger trees (average 111 years) in northern Idaho (Furniss et al. 1979). An average of 29 percent of those trees were attacked unsuccessfully, whereas 22 percent of the Montana trees survived attack.

Thus, in *unmanaged* stands, beetles attack groups of nearly mature or older trees. Generally attacks are more dense and successful in trees that are larger, more dominant, and more productive of resin (fig. 4 A and B). Less dominant trees are smaller and tend to be poor producers of resin (fig. 4 C). We theorize that good resin producers may be inherently more resistant (higher threshold of successful attack density) but may be killed at a higher rate because they at-

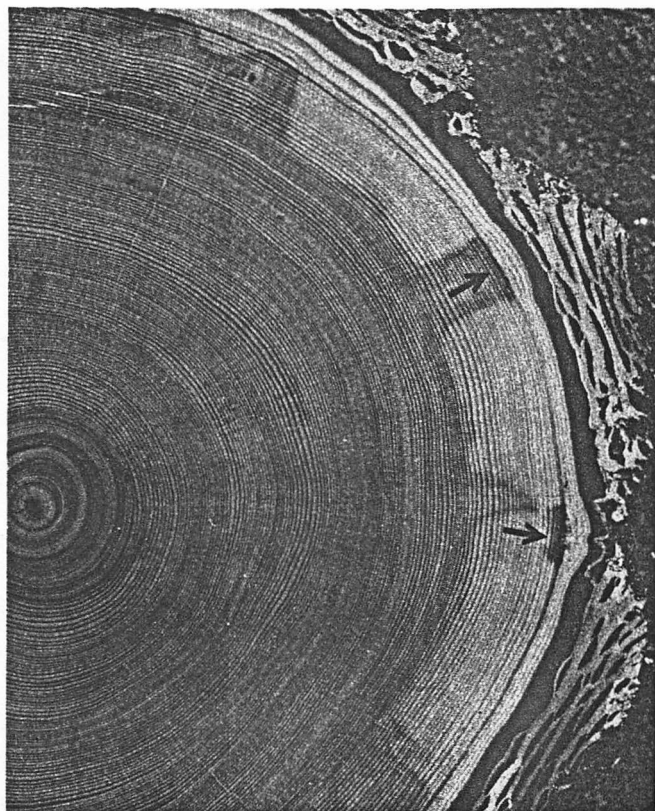


Figure 3.--Unsuccessful egg galleries in Douglas-fir covered over by callous growth. Note stimulation of growth rate in response to wounding.

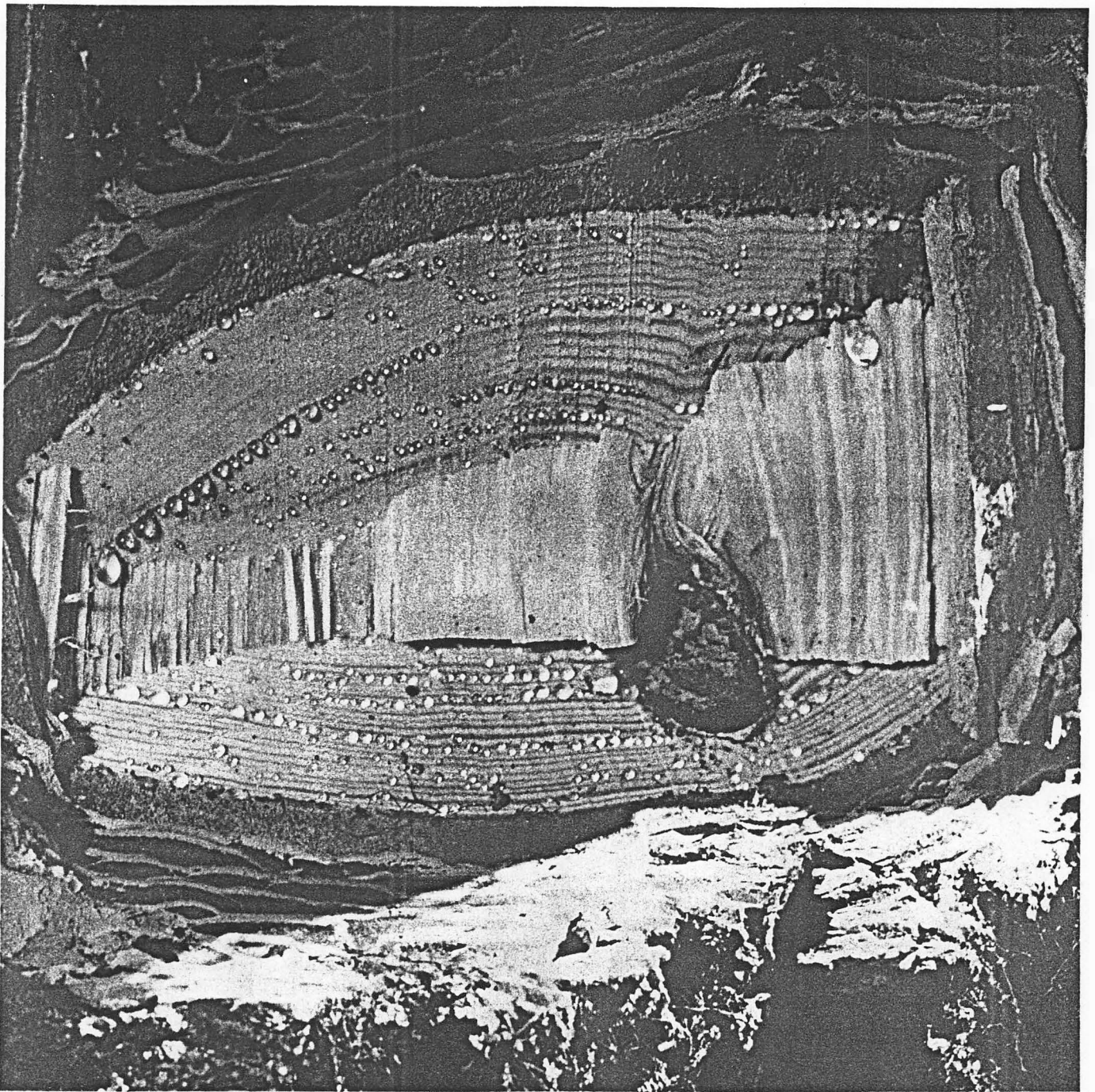
tract more beetles. Poor producers of resin may have a lower threshold of successful attack density, but that threshold is attained less often because the necessary resin odor is not present to synergize the aggregative pheromone of females that attack them (Furniss and Schmitz 1971). Concentration of monoterpenes varies greatly between trees (Hanover and Furniss 1966). For example, α -pinene--a strong synergist of aggregative pheromone--varies from 10 to 52 percent of the oleoresin

Table 1.--Frequencies and characteristics of categories of attacked trees, western Montana, 1963

Category	Percent	d.b.h.	10-year growth	Density of attacks ²
		inches	inches	number/ft ²
Susceptible	48	17.13 (356) ¹	0.285 (28)	10.9 (5)
Intermediate	30	16.21 (221)	0.274 (33)	5.2 (7)
Resistant	22	12.84 (162)	0.237 (27)	3.4 (27)

¹ Figures in parentheses are number of observations.

² Density of attack was determined by removal of bark from stems and counting all egg galleries.



content; 3-carene, a nonattractant, varies from 0 to 7 percent. We speculate that a tree with maximum α -pinene and minimum 3-carene content would aggregate more beetles if attacked than would a tree of minimum α -pinene and maximum 3-carene content.

Stand Characteristics

Density

We have never seen a DFB outbreak in residual stands after any kind of commercial cutting. In northern Idaho, representative stands (fig. 5) in which DFB

have killed trees contained a majority of DF and were stocked at 80 to 124 percent of normal (241 to 361 ft²/acre) (Furniss et al. 1979, and unpublished data).

Major factors involved in the susceptibility of dense DF stands are moisture stress and shaded stem environment. The relationship between moisture stress and tree mortality caused by bark beetles seems universal and is documented in literature (Furniss 1979, Rudinsky 1962 and 1966). A less well publicized factor is shading of stems in dense stands. DFB avoid the hot, sun-exposed portion of

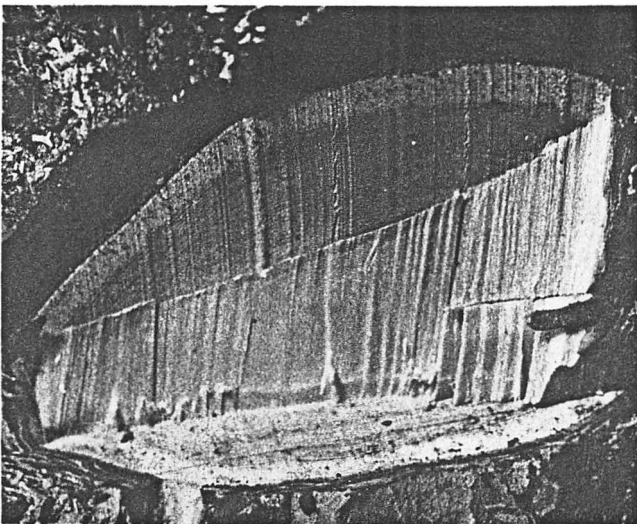
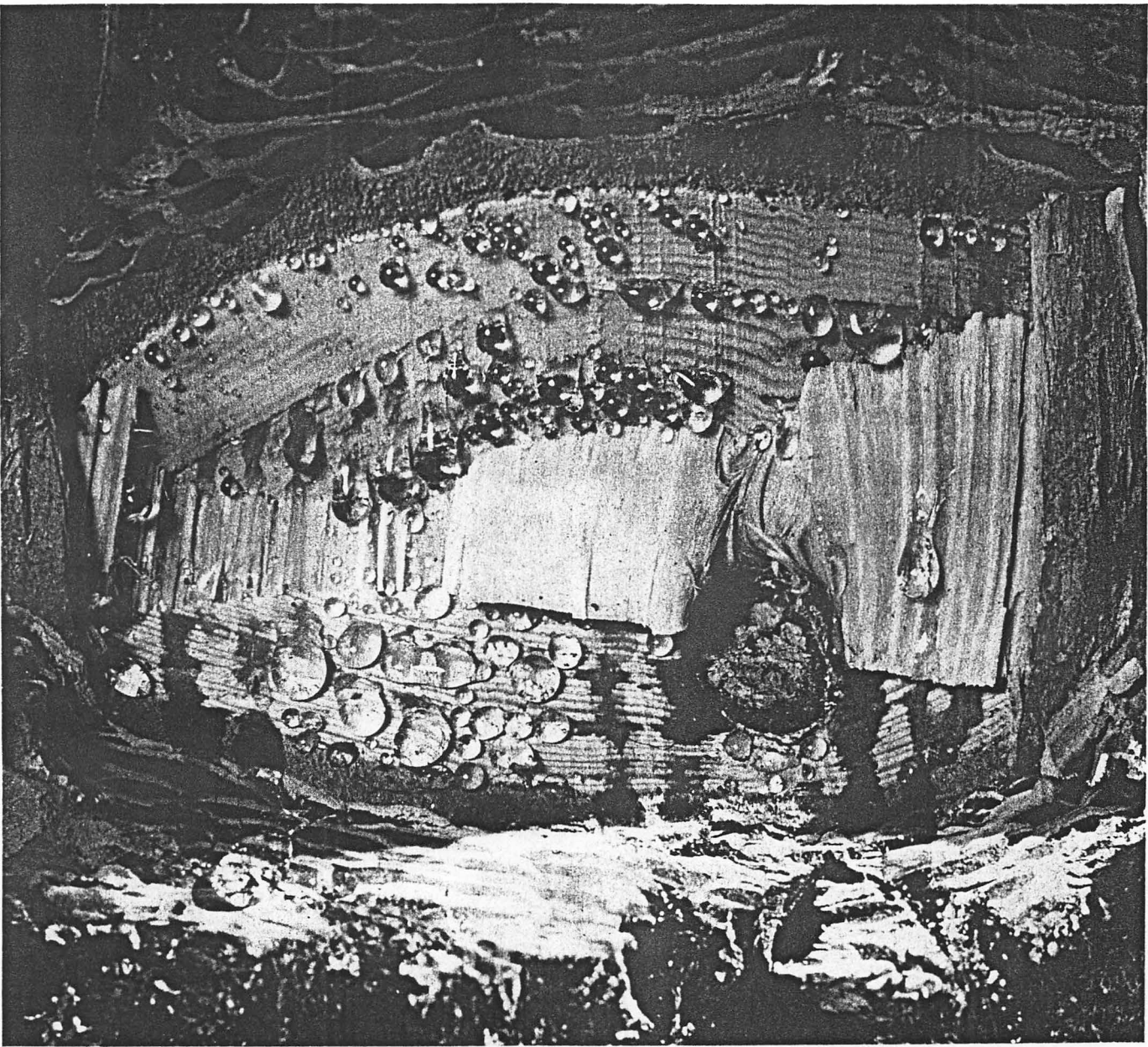


Figure 4.--Production of resin in codominant tree (A) 3 hours and (B) 3 days after chopping, and (C) absence of resin flow after 3 days in suppressed tree in same stand. Flathead National Forest, Montana.

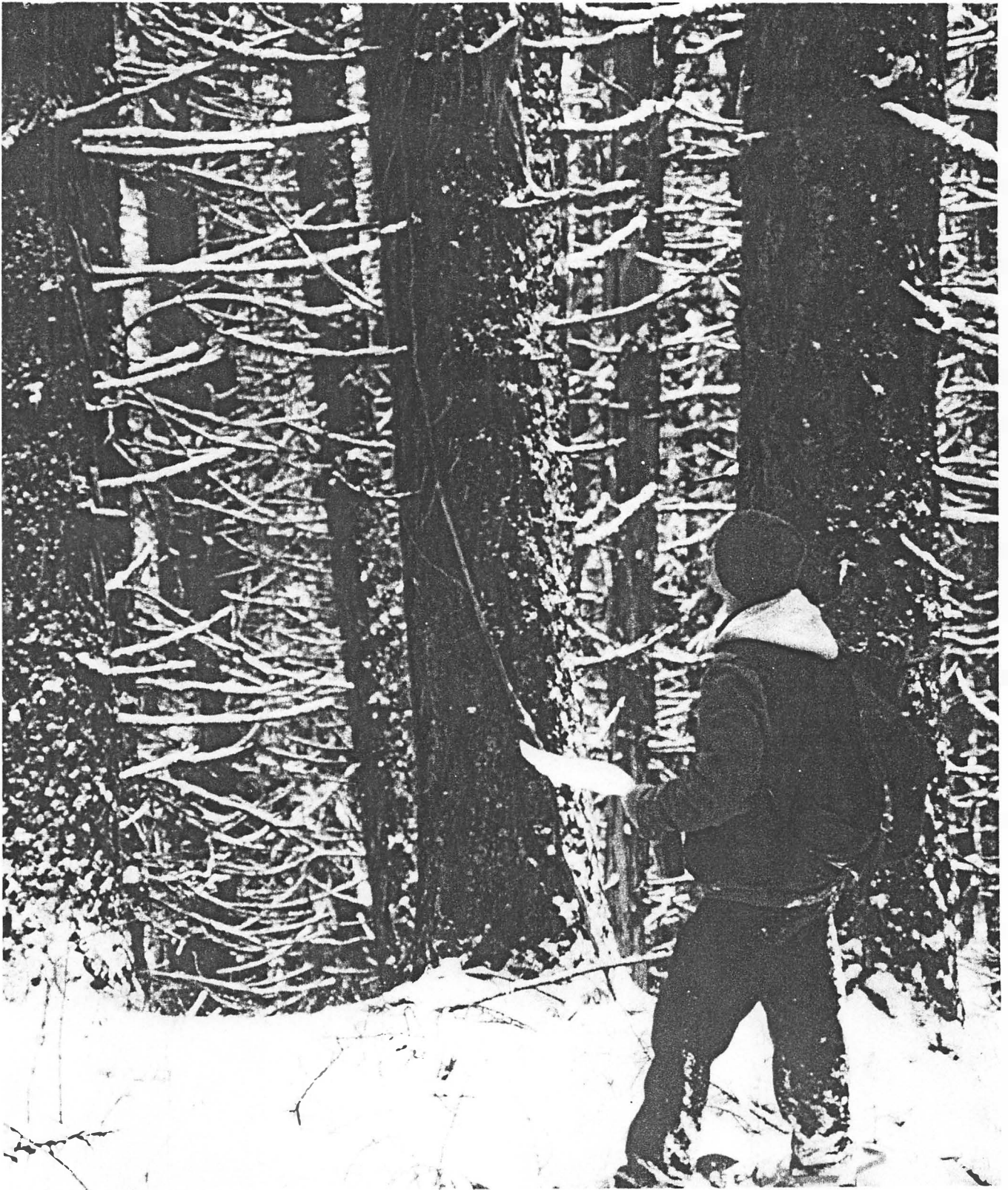


Figure 5.--Mature Douglas-fir stand in grand fir-pachistima habitat type, Clearwater River drainage, Idaho. High density combined with a preponderance of Douglas-fir approximately 90 years old or older combine to make such stands highly susceptible.

felled stems and attack less densely the lower boles of standing trees (Furniss 1962). After dense stands are cut, greater illumination and higher temperatures of stems discourage beetles from arresting there. This behavior of DFB, coupled with less moisture stress in residual trees in cutover stands, seems to account for the turnabout in susceptibility of those stands.

Species Diversity and Habitat Type

Mortality groups invariably contain more DF than other tree species. Thus, species diversity is a factor in susceptibility to DFB.

In drainages like the Clearwater River, DF often grows in dense communities that are rather homogeneous in age and species, particularly in grand fir and cedar habitat types. However, Douglas-fir is a wide-ranging species adapted to diverse environments. In northern and central Idaho, DF is recognized as a climax or major seral species in 40 habitat types (Daubenmire and Daubenmire 1968, Steele et al. 1976, Steele et al. 1975). No systematic attempt has been made to rank habitat types by DFB hazard, but some impressions have been gained (R.A. Ryker, USDA Forest Service, Boise, Idaho, personal communication).

For example, two DF habitat types that are not associated with excessive DF damage are *Pseudotsuga menziesii*/*Carex geyeri*-*Artemisia tridentata* and *P. menziesii*/*C. geyeri*-*Symphoricarpos oreophilus*. The former is capable of supporting only 80 percent normal stocking--barely the threshold density of mortality groups that we have inventoried in more susceptible habitat types, such as grand fir/pachistima and western redcedar/pachistima. Similarly, the *P. menziesii*/*C. geyeri*-*S. oreophilus* habitat type tends not to support closed stands because presence of *C. geyeri* often restricts regeneration of trees.

Frequently, DF habitat types of the series *Spirea betulifolia*, *Physocarpus malvaceus*, and *Symphoricarpos albus* contain stands with a good mixture of ponderosa pine. This mixture restricts DFB mortality to dense, older groups of DF of limited area, particularly during droughty years. Although DF occurs in northern and central Idaho as a major seral species in 10 subalpine fir habitat types, major DFB outbreaks have not occurred there, possibly because of their colder climate.

Tree Age

The average age of hundreds of DFB-killed trees that we have examined exceeds 120 years. Age of attacked trees

varies with locality and population pressure, however. During a recent outbreak in the Clearwater River drainage, some very dense stands containing trees 80 years old or less were attacked. Such young trees seldom die from attack, however.

In an earlier study, attractant pheromone was applied to 18 younger (80 years) and 32 older (170 years) trees on the Boise National Forest, Idaho (Furniss et al. 1972). None of the younger trees was killed, whereas 41 percent of the mature trees were successfully attacked. Likewise, 6 of 13 (46 percent) 133-year-old frontal-baited trees were attacked successfully in the Clearwater drainage (Ringold et al. 1965).

Diseases

Dwarf Mistletoe

We have not observed a correlation between Douglas-fir dwarf mistletoe, *Arceuthobium douglasii* Engelm., and DFB susceptibility in Idaho. A similar situation exists with lodgepole pine and *A. americanum* (Nuttall), presumably because infected trees have thinner bark (McGregor 1978).

We speculate that severe infection of DF by *A. douglasii* may result in reduced resin production (Weir 1916), making the affected tree less attractive to DFB. In any case, we have not seen any preferential association of DFB with dwarf mistletoe-infected DF; and we have noted poor brood production and spindly larval mines in DF afflicted with very severe mistletoe infection.

However, a possible relationship between *A. douglasii* and DFB has been reported in the Northwest (Weir 1916) and the southern Rocky Mountains (Stevens and Hawksworth 1970). To resolve the question, ratios of frequency of DFB infestation in the two categories of host trees need to be determined. We will report such information for stands in the Clearwater River and Boise River drainages when fieldwork is completed.

Root Diseases

A tie seems to exist between DFB and root diseases, but the firmness of the knot is hard to measure. Trees infected with root diseases often lack disease symptoms (Partridge and Miller 1972). Excavating the root system of a mature DF is a formidable job but is expedited by detonating explosive charges around the roots of felled trees (Miller and Partridge 1973) (fig. 6). Even so, it is feasible to examine only relatively little of the root

system if many trees are involved. Then, too, we wonder if incipient root disease may not develop more rapidly when the host tree dies. That would introduce a bias relative to uninfested trees that contained similar incipient infections.



Figure 6.--Preparation for blasting to excavate dirt from around roots to aid in examination for root rot infection.

Nonetheless, some evidence of an association of root disease and susceptibility to DFB has been developed (Furniss et al. 1979b). In that exploratory study, four trees were selected from each of two infested groups. Each set of trees represented the following conditions: susceptible (readily killed), intermediate (some larval mines present, but resinosis evident), resistant (no larval mines, trees survived), and not attacked. Amount of root disease was generally correlated with success of DFB attack. *Armillaria mellea* (Vahl. ex Fr.) Quel was the most frequently observed pathogen. Three trees with roots 70 to 90 percent killed were successfully invaded by beetles. Two with 30 to 40 percent of their roots killed had mostly unsuccessful attacks, and one tree with no visible diseased roots had no attacks. These trees were about 100 years old, growing in a grand fir-pachistima habitat type and in well-developed, fertile soil.

Onset of root disease in mature trees probably contributes to their susceptibility by increasing moisture stress (Vit   and Rudinsky 1962), but we have examined too many infested DF that had no evident symptoms to believe that root disease is obligatory. Rather, we view susceptibility as the product of complex relationships involving numerous factors, important among which is root disease.

Injuries

Fire

Mainly because of the 1933 Tillamook fire in Oregon, fire injury has been in-

ferred to be an important DFB susceptibility factor. After that exceptionally large fire, 200 million board feet of green DF were killed by beetles that had bred in fire-injured trees (R. L. Furniss 1941). However, no similar DFB outbreak associated with fire has been recorded in literature.

In a smaller fire, heat injury made a majority of trees susceptible to DFB attack (increasing with tree diameter and severity of injury short of death), but attack density, success, and infested height were low (Furniss 1965). We speculate that odors emitted from fire-injured trees are a source of attraction to beetles. Larger trees may be more attractive visually as well as in amount of odor. Whatever the case, many fire-injured trees retained sufficient resistance to survive. The DFB population was unable to expand and infest green trees surrounding the fire.

Wind and Snow

Windthrow caused by intense windstorms is fairly common in coastal areas and in the Northern Rocky Mountains where trees are large. By contrast, trees in the Southern Rocky Mountains are often shorter and grow on rockier soil; so they are more windfirm. Windfelled trees are attractive to DFB, more so if they are recently felled, large, and shaded (McMullen and Atkins 1962, Furniss 1962).

Accumulation of moist, heavy snow sometimes breaks the tops out of trees and subjects them to DFB infestation. Attracted beetles spill over into surrounding trees, creating typical mortality groups. This susceptibility factor is poorly publicized, and we rate it important in the Clearwater River drainages in northern Idaho. Classification of susceptibility in that area should provide for possible sudden increase in DFB infestation as a result of storm damage. Areas of storm hazard might be mapped with aid of a meteorologist, although we have not explored that possibility.

Defoliation

Much like the case of mistletoe infection, insect-caused defoliation of DF has been linked circumstantially with DFB susceptibility. Recently such a link was reported for Douglas-fir tussock moth (Berryman and Wright 1978). Although proportional occurrence of DFB mortality in defoliated and undefoliated trees was not reported, defoliation was shown to result in increased brood production and increased rate of tree mortality. A less well documented relationship between DF defoliated by western spruce budworm and

DFB susceptibility has been reported periodically in annual forest insect survey reports of the USDA Forest Service and the Canadian Forestry Service.

Verbal Model

The following verbal model (Furniss et al. 1979) is proposed to explain the functioning of factors affecting DF abundance and susceptibility of host trees.

Disturbances (e.g., windstorms and, to a lesser extent, fire) contribute to increased DFB populations. When such disturbances cease, beetles seek out and attack live trees; their success depends upon the susceptibility of the attacked trees. The proportion of Douglas-fir in a stand, and stand density and age are positively correlated with susceptibility. Any of those factors can limit DFB damage. Trees broken by weight of snow, stressed by drought, infected with root rots, or possibly defoliated by tussock moths are susceptible and may contribute to furtherance of the outbreak.

As susceptible trees are killed by beetles, stand density is relieved by logging, or as environmental conditions improve (favoring growth and water relations), resistance to population expansion mounts.

Size of infested groups declines and a higher proportion of attacked trees may survive. Numbers of natural enemies appear to be independent of prey density; influence of enemies increases after the bark beetle population subsides. Populations are maintained at an endemic level primarily by tree resistance and natural enemies.

ACQUISITION OF DATA

The following procedures were developed in the Clearwater River drainage. They are being applied to additional areas in that drainage and in the Boise River drainage where the rate of DFB infestation has been above normal in recent years.

Selection of Stands

We are concentrating our attention in areas where extensive unmanaged stands are available. The fact that cutover stands have no DFB damage to sample should not be passed over lightly by the reader.

Two steps are involved:

Step 1--We examined Idaho insect survey reports for general location of DFB mor-

talities. Mortality as old as 3 years is satisfactory for sampling. Then we obtained detailed aerial survey maps for the areas of interest from the agencies that conducted the damage surveys. Shown on those maps are the approximate locations and size of groups of DF having symptomatic reddened foliage.

Step 2--We observed candidate areas from aircraft to confirm their suitability for sampling and to obtain oblique stereo 35-mm color slides (Walsh and Hall 1978). The general area was photographed, slightly overlapping the sides of subsequent photo pairs. The center of interest of each photo pair was a lateral ridge or a drainage. The bottom and top of each photo spanned the width of the area to be sampled. For example, we exposed 24 stereo pairs to photograph a 16×2 mi (26×3.2 km) zone bordering the Selway River. The aircraft flew above the river at 6,300 ft (1,920 m) elevation; the landscape varied from 1,600 ft (488 m) at the river to 5,600 ft (1,707 m) at the top of the slope. That is steep country, characteristic of many areas where DF grows, and is one reason why the saw has not yet found the stands where the DFB has caught our attention.

Then we flew back over the same course at 5,300 ft (1,615 m) elevation and selectively photographed areas of intense damage at larger scale. The smaller scale oblique stereo photos were taken to orient the larger scale photos and to aid crews in traveling to groups that they couldn't see on the ground; the larger scale photos were used to select locations of sample plots in mortality groups and green stands.

Field Sampling

We had hoped to sample areas where stands had been delineated and inventoried by the managing agency. That would have provided us existing data on green stands, including the area encompassed by each sampled stand with which to weight the variable radius plot data (Daniels et al. 1979). However, such information was not available in areas of DFB mortality that we wished to sample.

Crew Organization

Crews consisted of three persons each. They were provided planimetric maps of $1/2$ inch = 1 mi (1.26 cm = 1.61 km) scale for general orientation; U.S. Geological Survey 7- $1/2$ min quadrangle maps (1:24,000 scale) with 40-ft (12-m) contours and approximate locations of groups and plots, and route of travel; oblique stereo 35-mm color slides of the day's work area; and

1:14,840 scale vertical stereophotos (for orientation). Wherever possible, crews were transported--sometimes by helicopter--to a starting point at high elevation where they worked their way down ridges to the sample plots. Often they had to be transported by raft across rivers, such as the Selway, at the conclusion of the day's sampling.

Duties of the three crewmembers were as follows, although shifting of assignments was permitted.

- (1) Locate and establish plots; operate Relascope³; determine aspect, slope, topographic position; determine height of tallest DF; determine habitat type; describe soil.
- (2) Record data; determine crown class, crown ratio; observe mistletoe and crown ailments, including defoliation; help with increment boring.
- (3) Paint numbers on trees; measure d.b.h. of plot trees; determine species of plot trees; observe root rot and stem diseases; bore tallest DF for age, 10-year growth of largest and smallest trees of each species.

Variable radius plots (40-factor prism) were located approximately 50 m apart either within mortality groups or in stands free of mortality. Green stand plots were laid across (not along) contours. Each crew established 8 to 12 plots per day equally divided between mortality groups and green stands.

Variables Sampled

Variables sampled (or constructed from sample data) are shown in table 2. Descriptors were grouped as follows: tree related, stand related, or site or physiographic. The detail with which any factor could be examined and measured was limited to that which was possible while keeping time per plot well within 1 hour. Such exploratory effort was believed to be sufficient to capture significantly correlated relationships of a major sort. Later we may study some relationships in more detail, but the level of refinement will depend upon interest and need expressed by agencies involved with protection and management of the forest resource.

Most of the descriptors sampled are included commonly in stand inventories and other susceptibility studies. However, some explanation of our methodology involving soil, diseases, and habitat type may be helpful.

Soil was examined to a depth of approximately 40 in (1 m) by digging with a tile spade to 18 in (46 cm), then with an auger 3.25 in (8.3 cm) in diameter. We recorded depth of A horizon, depth at which rocks were encountered if present, depth to C horizon, texture (hard, soft) of surface of C horizon, and depth of volcanic ash if present.

Tree diseases were identified symptomatically (Partridge 1974) and recorded as present or absent except for dwarf mistletoe, which was rated according to the method proposed by Hawksworth (1977). Time permitted chopping into root crowns only if external symptoms were visible.

Habitat type was determined for plots in the main Clearwater River drainage using Daubenmire and Daubenmire (1968). For the Selway River and Boise River drainages, we referred to Steele et al. (1975, 1976). Whenever vegetation on plots indicated that succession had been affected by relatively recent disturbance (fire, grazing), adjacent, less disturbed areas were observed to arrive at a classification.

ANALYSES OF DATA

Plot data were analyzed by the SCREEN computer program (Hamilton and Wendt 1975) to determine independent variables correlated with either presence or absence of mortality. Then, correlated variables were analyzed by the RISK computer program (Hamilton 1974, Hamilton and Edwards 1976) to obtain probabilities of mortality for combinations of descriptors.

The SCREEN program readily accommodates a large number of independent variables (mortality or green stand). Each variable can be divided into eight or fewer classes that need not be equal in size. Care is needed in setting class intervals for variables that may be clumped, otherwise significant relationships may be masked. Setting intervals is best accomplished by listing or plotting frequencies of values in order to identify natural class limits.

The RISK program computes a numerical value from 0 to 1--proportional to the degree of risk of mortality--for any combination of significant variables. This procedure provides a convenient means of stratifying stands by degree of risk of DFB mortality.

³ The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Table 2.--Variables measured to correlate with presence or absence of Douglas-fir beetle mortality

Tree Descriptors
Species
d.b.h.
Crown ratio
Crown class including broken top
10-yr growth
Height
Age
Infestation class (not infested, successful, unsuccessful)
Mistletoe
Root disease
Stand and Site
Mortality present or absent
Habitat type
Elevation
Aspect
Slope
Topographic position
Proportion of Douglas-fir
Basal area, total
Basal area, Douglas-fir
Crown competition factor
Disturbances (nearby root disease center, windfall, snowbreak)
Soil (A horizon, depth to C, quality of surface of C., rocks present or absent, depth of volcanic ash)
Area of mortality or green stand (and number of samples)
Number of dead trees per group

Example

The described methodology was tested in 1977 in Shattuck Creek drainage, Latah County, Idaho. The study area consisted of a dense, mature second-growth forest of the cedar-pachistima and grand fir-pachistima habitat types. Areas occupied by DF mortality and stands free of mortality were determined during sampling and from reference to aerial photos and topographic maps. For comparison, we computed risk with and without weighting the plots by estimates of the areas they represented. Daniels et al. (1979) describe similar procedures. Like their published example, ours is intended only to illustrate. We plan a more vigorous presentation when fieldwork is completed. That work is taking more detailed account of a wider range of variables, including proportion of DF, stand age, stand density, soil, diseases, and habitat types.

In our example--which involved a rather homogeneous area without a wide range of density, age, and tree species--the SCREEN program identified the most prevalent crown class as being significantly correlated ($p = 0.05$) with occurrence of mortality. Habitat type and slope were only significant at the 0.50 level of probability but are included for sake of demonstration. Table 3 contains test probabilities for combinations of those variables using unweighted and weighted

samples. The most susceptible stands had a high proportion of more dominant trees and occurred on steeper slopes in the cedar-pachistima habitat type.

The importance of weighting samples by the inverse of the sampling intensity is readily apparent from the reduction of probabilities and changes in rankings. Even a rough estimate of areas of mortality and green stands is better than assuming that they are equal.

CONCLUSIONS

Factors underlying DFB susceptibility have been discussed and incorporated into a verbal model explaining changes in DFB populations and DF mortality. Understanding the way those factors function is prerequisite to developing a versatile stand susceptibility classification.

Three universally present factors--stand density, stand age, and proportion of DF--are directly correlated with mortality. Each of those factors can limit mortality. For example, a dense stand of young DF (less than 80 years) is not susceptible to killing by DFB. Simplistically, the potential for DFB damage could be determined by summing numerical "penalties" for those three variables in a manner similar to that suggested for spruce beetle (Schmid and Frye 1976).

Table 3.--Probability of occurrence of Douglas-fir beetle in stands having selected combinations of prevailing crown class, habitat type, and slope

Significant independent variable ¹			Probability of mortality ³	
Prevailing crown class (CC)	Habitat type (HT)	Slope (S)	Not weighted ²	Weighted
1	1	20	0.60	0.14
2	1	20	.52	.03
3	1	20	.44	.01
4	1	20	.36	.01
1	2	20	.84	.42
2	2	20	.79	.12
3	2	20	.73	.03
4	2	20	.67	.01
1	1	10	.65	.08
1	2	10	.87	.28
1	1	30	.56	.23
1	2	30	.82	.57
3	1	10	.49	.01
3	2	10	.77	.01
3	1	30	.39	.01
3	2	30	.70	.05

¹ The independent variables were: crown class (1 = dominant, 2 = codominant, 3 = intermediate, 4 = suppressed); habitat type: (1 = grand fir-pachistima, 2 = cedar-pachistima); slope is in degrees.

² Data from mortality and green stands were weighted by the inverse of their sampling intensities. Weight for mortality data was 24 acres/31 plots = 0.77; weight for green stand data was 380 acres/69 plots = 5.51.

³ Regression coefficients for mortality model were (not weighted, weighted): prevailing crown class (-0.330072, -1.64255), habitat type (1.26117, 1.50144), slope (-0.0192382, 0.0608783), constant (1.3294, -1.41611).

$$p = 1 + e^{-(\beta_0 + \beta_1 CC + \beta_2 HT + \beta_3 S)} - 1$$

However, additional factors, some subject to chance, are implicated in the probability of occurrence of DFB damage. Methods by which these diverse factors are being sampled and analyzed have been presented. Care is being taken to obtain data in a manner compatible with that used by resource agencies in Idaho to assure acceptance and applicability of the method. When this work is completed, the method of classifying DFB susceptibility by application of the logistic function to stand and site variables correlated with mortality should help protection specialists and resource managers to better identify the stands most in need of treatment to prevent mortality caused by the Douglas-fir beetle.

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